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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

AUTOMATING ASW FUSION

by

James C. Pabelico

June 2011

Thesis Advisor:
Second Reader:

James Eagle
Alan Washburn

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AUTOMATING ASW FUSION

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Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN APPLIED SCIENCE
(OPERATIONS RESEARCH)**

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

This thesis examines ASW eFusion, an anti-submarine warfare (ASW) tactical decision aid (TDA) that utilizes Kalman filtering to improve battlespace awareness by simplifying and automating the track management process involved in anti-submarine warfare (ASW) watchstanding operations. While this program can currently help the ASW commander manage uncertainty and make better tactical decisions, the program has several limitations. Commander, Anti-Submarine Warfare Force U.S. Third Fleet/Commander, Task Force THREE FOUR (CTF-34), seeks to utilize ASW eFusion's playback feature to re-analyze ASW missions by incorporating friendly (Blue) submarine detections into historical target tracks generated by other ASW sensors. The problem is that, the program exhibits several system timing problems when the operator attempts to insert time-late observation data. This thesis will evaluate ASW eFusion's problematic ability to handle time-late reports, prescribe working solutions, and investigate methods to improve the program's user interface for use on the tactical watch floor.

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LIST OF ACRONYMS AND ABBREVIATIONS

This following is a list of commonly used acronyms and abbreviations that can be utilized for deciphering concepts and references contain herein.

AOR	Area of Responsibility
AOU	Area of Uncertainty
ASW	Anti-submarine Warfare
ASW eFusion	Anti-Submarine Warfare Electronic Fusion
ASWEX	Anti-Submarine Warfare Exercise
ASWO	Anti-Submarine Warfare Officer
BAMS	Broad Area Maritime Surveillance
BGIE	Battle Group Inport Exercise
BWC	Battle Watch Captain
CNA	Center for Naval Analyses
CSG	Carrier Strike Group
CTF-34	Commander Task Force Three Four
CTP	Common Tactical Picture
DS or dshock	Dimensionless Shock
EKF	Extended Kalman Filter
FLIR	Forward Looking Infra-Red
GCCS-M	Global Command and Control System Maritime
ISR	Intelligence, Surveillance, and Reconnaissance
MAD	Magnetic Anomaly Detector
MDA	Maritime Domain Awareness
MPC	Mission Planning Cell
MTST	Maneuvering Target Statistical Tracker
FOC	Furthest On Circle
LOB	Line of Bearing
LosCon	Lost Contact
NTDS	Naval Tactical Display System

SCC	Sea Combat Commander
SME	Subject Matter Expert
TACTRAGRUPAC	Tactical Training Group Pacific
TASW	Theater Anti-Submarine Warfare
TDA	Tactical Decision Aid
UAV	Unmanned Aerial Vehicle
UUV	Unmanned Underwater Vehicle
USW	Undersea Warfare
USW-DSS	Undersea Warfare Decision Support System

EXECUTIVE SUMMARY

ASW remains an art.¹ For successful theater ASW and strike group operations, it is essential that the location of a submerged threat is known, at least approximately, at all times. This can be achieved through persistent intelligence, surveillance, and reconnaissance (ISR) and the proactive management of contact track and sensor data. In its present form, ASW eFusion, an anti-submarine warfare (ASW) tactical decision aid (TDA), can support the ASW commander to better manage uncertainty and ultimately make better tactical decisions. Specifically, this Microsoft Excel-based application enables the ASW watchstander to better manage, organize, fuse, and display contact data. However, as Commander, Anti-Submarine Warfare Force U.S. Third Fleet/Commander, Task Force THREE FOUR (CTF-34) and this research has identified, the program has its limitations.

CTF-34, which conducts theater ASW operations, seeks to utilize ASW eFusion's playback feature to re-analyze ASW missions by incorporating friendly (Blue) submarine detections into historical target tracks generated by other ASW sensors. The problem is that, CTF-34 has encountered several system timing problems when attempting to insert time-late observation data from friendly (Blue) submarines. This thesis evaluated ASW eFusion's current ability to handle time-late reports, prescribed working solutions, and investigated methods to improve the program's user interface for use on the tactical watch floor.

With the fixes identified in this research, CTF-34 and other prospective fleet users can benefit from ASW eFusion's improved functionality. Specifically, the program's enhancements can aid tactical watchstanders in support of real-time ASW operations, as well as help the mission planner or data analyst re-analyze significant ASW events in the past. To that end, the ASW commander and his staff will be better equipped with the tools necessary to achieve maritime domain awareness, enabling successful ASW operations.

¹ Joelle J. Mann, "ASW Fusion on a PC," *Naval Postgraduate School Master's Thesis* (June 2004), 11.

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Most importantly, I would like to thank my beautiful wife Mary Ann and two sons Andrew and Mikey. My wife is my best friend. She keeps me grounded and is always there to help me finish what I start. My boys are my motivation. They keep me young at heart and centered on helping shape the future. I love you all very much and look forward to our next chapter of Navy life.

James C. Pabelico

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I. INTRODUCTION

This thesis examines the utility of ASW eFusion, an anti-submarine warfare (ASW) tactical decision aid (TDA) designed to improve battlespace awareness by simplifying and automating the track management process involved in anti-submarine warfare (ASW) watchstanding operations. Specifically, this Microsoft Excel-based application enables the ASW watchstander to better manage, organize, fuse, and display contact data.² In the event of a lost contact or periods of no contact, this planning tool can also assist the ASW Officer (ASWO) predict target motion by estimating a submarine's intended track and generating an area of uncertainty (AOU) to help focus search efforts. While this program can sufficiently help the ASW commander manage uncertainty and make better tactical decisions, the program has several limitations.

Commander, Anti-Submarine Warfare Force U.S. Third Fleet/Commander, Task Force THREE FOUR (CTF-34), engaged in theater ASW operations, recognizes the value ASW eFusion adds to the watchstanding process, but has encountered difficulties using the application. One of the key features of the program is its ability to replay past ASW events using historical track data. CTF-34 seeks to utilize this playback feature to re-analyze ASW missions by incorporating friendly (Blue) submarine detections into historical target tracks generated by other ASW sensors. However, CTF-34 encountered several operator interface problems when attempting to insert time-late observation data from friendly (Blue) submarines. According to the CTF-34 Training and Plans Officer, to be of significant tactical utility, this program must be able to properly process time-late contact reports from submarines, which are sometimes delayed due to the submarine's restricted availability for communication.³ This thesis will evaluate ASW eFusion's current ability to handle time-late reports, prescribe working solutions, and investigate methods to improve the program's user interface for use on the tactical watch floor.

² Kevin M. Kirk, ASW eFusion: Description and User's Manual (Draft Version), CNA, Alexandria, Virginia, November 2005.

³ George C. Wright, 2011, private communication.

The following sections describe the challenges of establishing battlespace awareness in ASW, the origin of ASW eFusion, and how the program can be used to simplify and automate various ASW watchstander activities.

A. MANAGING THE ASW BATTLESPACE

Maritime domain awareness (MDA) will be achieved by improving our ability to collect, fuse, analyze, display, and disseminate actionable information and intelligence to operational commanders.⁴ To that end, successful theater ASW (TASW) operations and the survival of the carrier strike group (CSG) require persistent intelligence, surveillance, and reconnaissance (ISR) and the systematic management of ASW sensor information shown in Figure 1. ISR is important not only for the traditional purpose of intelligence collection; it also serves as a precursor and enabler for the ASW mission.⁵

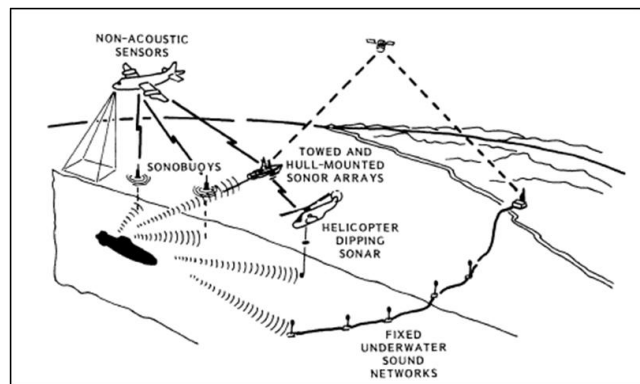


Figure 1. Theater ASW platforms and sensors

ASW is an art of warfare that requires a collective team effort. Specifically, it demands the coordination of a wide variety of organic and nonorganic platforms to detect, track, and identify elusive submerged targets hidden in a vast surveillance volume.⁶ Providing long-range ASW, multi-mission maritime aircraft such as the P-8A

⁴ Department of Homeland Security, “National Plan to Achieve Maritime Domain Awareness for the National Strategy for Maritime Security” (October 2005).

⁵ Department of the Navy, “The Navy Unmanned Undersea Vehicle (UUV) Master Plan,” (November 2004): 9–11.

⁶ Edward L. Waltz and Dennis M. Buede, “Data Fusion and Decision Support for Command and Control,” *IEEE Transactions on Systems, Man, and Cybernetics*, vol. SMC-16, no. 6 (November/December 1986): 865–867.

Poseidon and P-3C Orion provide the over-the-horizon ASW sensing capability for the Navy. Additionally, defending the carrier strike group from immediate ASW threats is the MH-60R Seahawk helicopter. Future capabilities, including the Broad Area Maritime Surveillance (BAMS) unmanned aerial vehicle (UAV) system, will complement these platforms by providing continuous maritime surveillance for Navy.⁷ Collectively these airborne assets are capable of deploying air launched sonobuoys, employing nonacoustic sensors such as radar, forward looking infra-red (FLIR), and magnetic anomaly detectors (MAD) to detect and track submarines.

Guarding the ocean's surface are ASW equipped frigates, destroyers, and cruisers deployed at the outer edge of the carrier strike group to form an outer surveillance barrier. These combatants are routinely outfitted with towed array and hull-mounted sonars to locate and track submerged targets. In addition, the growing use of unmanned underwater vehicles (UUV) acts as a force multiplier by increasing the number of sensors in the battlespace.⁸

The challenge for ASW commanders and their respective staffs is that the volume of information to be collected, sorted, and acted upon poses a formidable task for the ASW commander and his staff. As a result, data fusion and proactive management of the growing amount of sensor data is necessary to provide the ASW commander with a common tactical picture (CTP) of the ASW battlespace. Data fusion involves the integration of information from a variety of sensors and sources to develop the best possible perception of the military situation.⁹ Further, the fusion process includes the collection, management, organization, and merging of data to create and display current (and past) situations. This includes ASW orders of battle of friendly and hostile forces, integration of acoustic and nonacoustic sensor data, events of tactical interest, and intelligence data as it relates to past, present, and predicted future movement of an enemy submarine.

⁷ P-8A Poseidon, U.S. Navy fact file.

⁸ Department of the Navy. "The Navy Unmanned Undersea Vehicle (UUV) Master Plan," (November 2004): 1-9.

⁹ Waltz and Buede, "Data Fusion and Decision Support for Command and Control."

Automation of the fusion process and quantitative evaluation of alternative actions are required for the decision makers.¹⁰ Assisting the ASW commander to make timely and informed decisions are sophisticated battle management systems like the Global Command and Control System – Maritime (GCCS-M) and the Undersea Warfare Decision Support System (USW-DSS). These systems enable the ASW watchstander to combine observations from various platforms with fixed underwater sonar sensors, visual sightings, periscope detections, emitter detections, national intelligence sources, and other task force detections to automatically fuse, correlate, filter, maintain, and display hostile submarine tracks.¹¹ While GCCS-M and USW-DSS represent the latest advancements in automation, it is essential to note that the human decision maker performs the most critical role in data fusion. Specifically, he must carefully analyze all the information these systems have processed and determine the best course of action.

B. THE WATCH

Embarked in the “Zulu” module on the aircraft carrier is the Sea Combat Commander (SCC). The SCC is the operational commander of all surface and subsurface assets within a carrier strike group. Further, the SCC is responsible to the Strike Group Commander for the overall planning and execution of maritime operations including Surface and Subsurface Warfare; Maritime Interdiction Operations; Mine Warfare; Explosive Ordnance Disposal and Force Protection.¹² The SCC’s main objective in ASW is to ensure that hostile attack submarines do not, unexpectedly, enter the carrier’s outer defense zone undetected or unidentified. This requires that, SCC is kept apprised of the location of all subsurface threats at all times. To build battlespace awareness, SCC watchstanders collect and plot the observations from various ASW platforms within the

¹⁰ Waltz and Buede, “Data Fusion and Decision Support for Command and Control,” 866.

¹¹ Global Command and Control System – Maritime.
[http://www.public.navy.mil/spawar/productsServices/Pages/GlobalCommandandControlSystem-Maritime\(GCCS-M\).aspx](http://www.public.navy.mil/spawar/productsServices/Pages/GlobalCommandandControlSystem-Maritime(GCCS-M).aspx) (accessed April 26, 2011).

¹² Destroyer Squadron Seven (CDS-7) (n.d.). *COMDESRON SEVEN – Official Site*. Retrieved May 1, 2011, from <http://www.public.navy.mil/surfor/cds7/Pages/default.aspx>.

strike group. This information is analyzed by the SCC to develop an understanding of the battlespace, from which he then determines the best course of action based on changes in the tactical situation.

1. Typical Watchstanding Responsibilities

Along with the use of advanced track management systems like GCCS-M and USW-DSS, the ASW watchstander still relies heavily on the use of manual plots and contact logs for record keeping and backup. The typical cycle of watchstanding activities begins when a contact report comes over secured chat or a voice circuit within the Zulu module. After receiving the report, the watchstander manually enters the data into a watch log and advises the ASWO or Battle Watch Captain (BWC) of the new information. Details of the contact report are transcribed onto a paper plot, written into a contact log for historical analysis, and then entered into a tactical display system, like GCCS-M.

In the past, the ASW Officer (ASWO) developed his situational awareness, using old-fashioned rice paper and makeshift tools to maintain an ASW Master Tactical Plot. Additionally, manual logs were used to discern long-term trends from subsurface contact data. A typical ASW Master Tactical Plot includes hand-drawn furthest-on circles (FOC) from the most recent contact report, as well as any significant geographic overlays and friendly force positions. To illustrate the ad hoc nature of the plotting process, sometimes a quarter was used to draw a circle around a contact's location, when no details about the accuracy of the contact's position were known.¹³ Clearly, methods of this type are vulnerable to inaccuracies and plotting errors. On the other hand, they provide simple ways to quickly to build situational awareness. After all recording and plotting is complete, the ASWO then analyzes the implications of the new contact report and decides if any action should be taken.

In summary, the watch officer's ability to make good tactical decisions is directly affected by the timeliness, accuracy, and practical limitations imposed by the manual

¹³ Mann, "ASW Fusion on a PC."

plot.¹⁴ While many of these manual processes have been refined over the years, there have also been improvements in tracking, correlation, and fusion methods to simplify and automate some of the ASW watchstander's manually intensive duties.

C. AUTOMATION FOR THE WATCHSTANDER

As tactical and strategic warfare has increased in speed, complexity, and scope, the requirements imposed on data fusion and decision support techniques have exceeded the capabilities of traditional manual techniques (plot boards, contact logs, display overlays, etc.).¹⁵ The following sections will introduce two ASW tactical decision aids, called LosCon and ASW eFusion. LosCon was developed in early 2004 by a Naval Postgraduate School master's degree student.¹⁶ In addition, ASW eFusion was created in January 2005 by the Center for Naval Analyses.¹⁷ Both of these programs represent the latest efforts to utilize Microsoft Excel-based applications and a statistical technique known as Kalman Filtering, to automate the management, organization, fusing and displaying of contact data.

1. DEVELOPMENT OF LOSCON

In 2004, U.S. Navy Ensign Joelle J. Mann from the Naval Postgraduate School (NPS) completed her Master's thesis entitled "ASW Fusion on a PC." Mann's research, in collaboration with Professor Alan Washburn of the Operations Research (OR) department at the Naval Postgraduate School (NPS), marked the first endeavor to automate the ASW watchstanding process using a Microsoft Excel-based application. The program, appropriately titled "LosCon," was designed to assist the ASW commander regain tactical control in a loss contact situation. LosCon used the Maneuvering Target Statistical Tracker (MTST) target motion model and employed Kalman filtering. Kalman

¹⁴ Kirk, ASW eFusion: Description and User's Manual (Draft Version).

¹⁵ Waltz and Buede, "Data Fusion and Decision Support for Command and Control." 865.

¹⁶ Mann, "ASW Fusion on a PC."

¹⁷ Kirk, ASW eFusion: Description and User's Manual (Draft Version).

filtering is a method of recursively estimating the state (often position and velocity) of an evading target using imperfect measurements.¹⁸

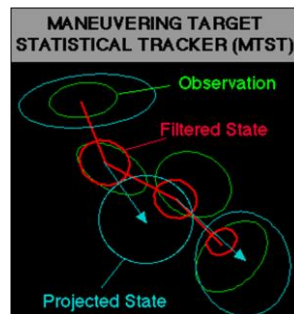


Figure 2. Maneuvering Target Statistical Tracker (MTST)

MTST was developed by Daniel H. Wagner Associates in the early 1980s and is utilized by the Navy as a Standard Tracker for at-sea targets.¹⁹ Utilizing historical observations of a target, LosCon could quickly compute an expanded AOU for any future time. This allowed commanders to estimate the size of the search area.²⁰ Figure 3 shows LosCon's map display and its ability to track up to three targets.

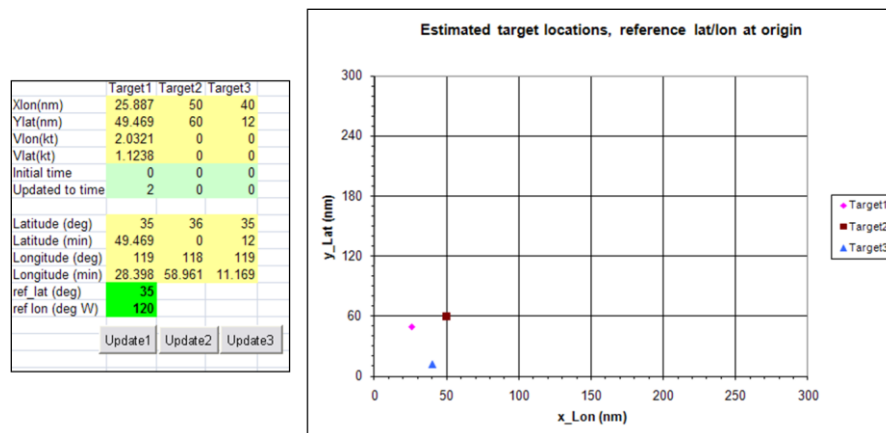


Figure 3. LosCon map display from the master spreadsheet

¹⁸ Mann, "ASW Fusion on a PC."

¹⁹ Daniel H. Wagner, "Naval Tactical Decision Aids." *Military Operation Research Lecture Notes*. September 1989.

²⁰ Ibid.

During LosCon's test phases, Mann deployed aboard the USS JOHN C STENNIS and USS MOBILE BAY to develop and refine its practicality. Put to the test, Mann observed LosCon's contribution following a loss of contact situation during the several ASW exercises. The following observation describes Mann's account of LosCon's practicality during a two-day ASW battle problem:

The search platforms made contact with the submarine and maintained contact for a few hours early in the problem. The searchers lost contact for several hours but had maritime patrol aircraft coming on station with sonobouy laying capabilities. Based on LosCon's predicted AOU for the time the aircraft would arrive, a search pattern was laid out. Less than a half hour into the search, the aircraft located the submarine near the center of the predicted AOU.²¹

While Mann's research demonstrated LosCon to be a helpful ASW tactical decision aid, the program's basic user interface required additional functionality to be a practical watchstanding tool.

2. ASW EFUSION ORIGIN

In 2005, software developer, Dr. Kevin M. Kirk, a Center for Naval Analyses (CNA) representative to Tactical Training Group Pacific (TACTRAGRUPAC), sought to expand upon Mann's research efforts. Utilizing the Kalman filtering software from LosCon and technical guidance from Professor Washburn, Dr. Kirk designed a tactical decision aid entitled "ASW eFusion." Related to LosCon, ASW eFusion sought to improve upon the manpower-intensive processes associated with the manual plot to enable the ASW commander and his staff to make quicker and more informed decisions.

ASW eFusion has improved user applications to help the operator simplify, organize, and automate contact data entry functions. At its core, the program makes use of LosCon's extended Kalman filtering algorithm to assist the watchstander in fusing the contact data, discounting false contacts, and estimating a target's most likely track and area of uncertainty (AOU).²² The program also has improved upon the mapping and

²¹ Mann, "ASW Fusion on a PC."

²² Kirk, ASW eFusion: Description and User's Manual (Draft Version).

display functions. Notably, a replay feature has been added to enable the operator to step forward or backward in time to examine past events. The software has also an increased capability to track up to four targets. In short, ASW eFusion is an enhanced version of LosCon.

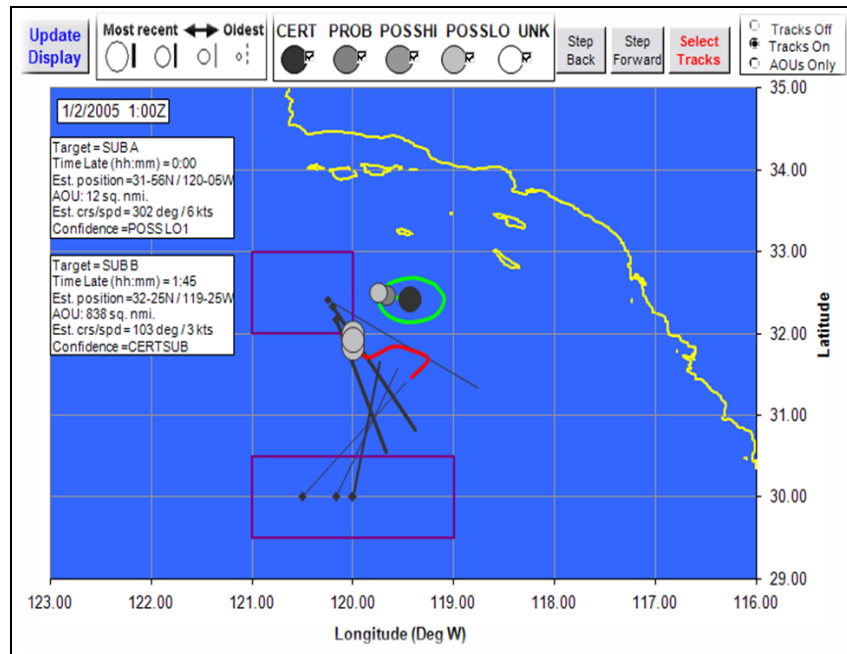


Figure 4. ASW eFusion Contact_Plot display

In the early development and testing stages of ASW eFusion, Dr. Kirk examined the program's feasibility during the USS CARL VINSON (CVN-70) and USS NIMITZ (CVN-68) Battle Group Inport Exercises (BGIEs) and two at-sea ASW exercises. During the VINSON BGIE in 2004, the program gained acceptance and popularity with the ASW watchstanders, as the software showcased its ability to quickly build situational awareness and predict target motion throughout the exercise. The following caveat describes Dr. Kirk's analysis of ASW eFusion's performance:

Post-mission analysis of the data revealed that that there were no false contacts used during the exercise. This greatly simplified the fusion and classification processes as almost all contacts could be readily associated with a specific threat submarine. Hence, the ASW eFusion software was able to generate very accurate tracks and AOU's for the threat submarines that the strike group could then avoid.²³

Following the VINSON BGIE, the next test for ASW eFusion took place at sea during the VINSON ASW Exercise (ASWEX). This test demonstrated how a lack of familiarity and training of the ASW eFusion software could reduce the utility of the program. During this exercise, Dr. Kirk's presence in the ASW module as a subject matter expert (SME) offered watchstanders valuable guidance and instruction on how to properly use the software. However, Dr. Kirk observed that when he was not available to train or mentor the watchstanders, they did generally a poor job of maintaining the contact log as they had little enthusiasm for what they viewed to be just another database to maintain.²⁴ Moreover, this demonstrated that if the watchstander does not proactively maintain and sort incoming contact data, then the ASW CTP can become cluttered with false contacts, degrading a commander's situational awareness.

The next test for ASW eFusion took place during the NIMITZ BGIE in March 2005. This experiment demonstrated ASW eFusion's ability to simplify and automate the contact reporting process. During this exercise, the ASWO took it upon himself to learn the software to maintain the program's tactical plot and contact reports. In doing so, the ASWO became proficient with the analytic and fusion capabilities of ASW eFusion, enabling the officer to discern operating patterns and assist in correlating contacts.²⁵ Additionally, due to the limited availability of oceanographic charts for the exercise area, the ASW watch team benefited from ASW eFusion's electronic overlays and mapping features to maintain situational awareness during the exercise.

In review, ASW eFusion represents a modest effort to expand upon the LosCon software developed by Mann. To be used effectively, the ASWO and his watchstanders

²³ Kirk, ASW eFusion: Description and User's Manual (Draft Version), 17–20.

²⁴ Ibid., 18.

²⁵ Ibid, 19.

must receive proper training and become familiar with the application prior to using the program. Further, when the program's contact log database is appropriately managed, ASW eFusion could quickly generate accurate tracks and AOU's, which could be utilized by the ASW commander and warfighter to increase ASW battlespace awareness.

The next section details the theoretical background of Kalman filtering and how it is applied in ASW eFusion for ASW. Subsequent chapters will examine the program's problematic method to process post-positional target data, identify potential solutions, and recommend improvements to increase the program's utility the tactical watch floor.

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II. KALMAN FILTERING

A. BACKGROUND

The next two chapters rely heavily on the *ASW eFusion User's Manual*, to provide the underlying basis for Kalman filtering and its application within ASW eFusion to update and manage track data.²⁶ For ASW operations, ASW eFusion can be utilized to automate the correlation, classification, and plotting of contact sensor data. Observations or contact reports from various sensor sources are fused using a statistical technique known as Kalman Filtering. The Kalman Filter (KF) used in this capacity, can assist the ASW commander predict a target's intended track and generate an area of uncertainty (AOU) to facilitate direct search efforts.

Kalman filtering is a method of estimating the current or future state of an evolving system from a sequence of “noisy” (i.e., inaccurate) measurements.²⁷ The Kalman filter recursively updates an estimate of the state of a system by processing a succession of measurements.²⁸ It also can keep unwanted noise (or bad data) from improperly influencing the estimate of the system state. For example, in ASW, there are inherent measurement uncertainties associated with all ASW sensors and platforms. On surface ships and submarines, there are known bearing errors associated with towed-array contacts, as well as, bearing and range errors associated with active sonar contacts. Airborne assets report also contacts with inherent inaccuracies associated with sonobuoy bearing error, radar, MAD and visual reports as well. Kalman filtering can be used to manage uncertainty and estimate location based on these types of uncertain measurements. In tracking a submerged target, the Kalman filter projects the system state to a future time based upon a model of the target's motion. Then, whenever a new measurement is observed, the Kalman filter corrects the predicted estimate of the system with this new, inaccurate, or noisy measurement.

²⁶ Kirk, ASW eFusion: Description and User's Manual (Draft Version), 7–14.

²⁷ James Eagle, “Kalman Filters,” (NPS 2010).

²⁸ Alan Washburn, “A Short Introduction to Kalman Filters” (NPS 2004).

1. Stochastic Variables

A Kalman filter represents the *system state* by a multivariate random normal variable, X , with a mean μ and covariance matrix Σ , denoted symbolically as:

$$X \sim N(\mu, \Sigma)$$

The Kalman filter repeatedly updates the mean and covariance matrix to account for both the target's movement and new measurements. Uncertainties are also associated with both measurements and movement; V and W represent the measurement and movement noise, respectively. Both measurement V and movement W noise are Gaussian, with mean values of zero. V and W are represented by the following probability distributions:

$$V \sim N(0, R)$$

$$W \sim N(0, Q)$$

R is the covariance of the *measurement noise*, and Q is the covariance of the *movement noise*. All of the computations associated with the Kalman filter that account for both motion and measurements are manipulations of X , V , and W .²⁹

2. Movement Matrix

The system state at some future time, X' , is predicted by the product of the movement matrix ϕ and the old state of the system X , summed with the error associated with movement W . The mathematical expression is given as:

$$X' = \phi X + W$$

The *movement matrix* ϕ describes the how the system's state changes over time. Two options are available within ASW eFusion to estimate how the target moves between measurements. The default option uses the Maneuvering Target Statistical Tracker (MTST) model, while the other option is based on the concept of furthest-on circles (FOC). Further discussion of the motion models can be found in Chapter III, Section B.

²⁹ Washburn, "A Short Introduction to Kalman Filters."

3. Measurement Matrix

Measurements \mathbf{Z} are related to the system state according to measurement (or observation) model:

$$\mathbf{Z} = \mathbf{H}\mathbf{X} + \mathbf{V}$$

\mathbf{H} is the *measurement matrix*, describing how measurements depend on the state \mathbf{X} , and recall that \mathbf{V} represents the measurement uncertainty.

Kalman filters assume that both the measurement model and system dynamics are linear functions of the state. However, if the measurement is a nonlinear function of the state variables, then the measurement matrix \mathbf{H} must be obtained by *linearizing* the nonlinear function.³⁰ When either of the models must be linearized, the new model is referred to as an *Extended Kalman Filter (EKF)*.³¹ While either the movement or measurement matrix models may be nonlinear, in ASW eFusion, nonlinearity only applies to bearing-only contact reports.

4. Kalman Gain

Recall that \mathbf{H} defines the measurement matrix, it follows that $\mathbf{H}\hat{\boldsymbol{\mu}}$ represents that mean or best guess of the measurement \mathbf{Z} . As a result, $(\mathbf{Z} - \mathbf{H}\hat{\boldsymbol{\mu}})$ is the “*shock*” to the system introduced by the measurements. The shock represents the difference between the measurement and what the Kalman filter expected the measurement to be based on past measurements.³² The Kalman filter then makes a correction to this best guess which is proportional to the shock. The proportionality factor used to determine the amount by which the estimate of the state is corrected is known as the *Kalman gain*, \mathbf{K} .

Kalman gain is defined by:

$$\mathbf{K} = \boldsymbol{\Sigma}^- \mathbf{H}^T (\mathbf{H} \boldsymbol{\Sigma}^- \mathbf{H}^T + \mathbf{R})^{-1}$$

³⁰ Washburn, “A Short Introduction to Kalman Filters.” 16.

³¹ Mann, “ASW Fusion on a PC.”

³² Washburn, “A Short Introduction to Kalman Filters.”

The “-” superscript indicates *a priori* estimates, which are those values that have been projected in time by the movement model, but have not yet been corrected by the measurements. The amount by which the estimate for the mean is corrected, based on the measurements is obtained by multiplying the Kalman gain \mathbf{K} , by the shock. Additionally, the estimate for the corrected mean $\boldsymbol{\mu}$ is updated by summing the product of the Kalman gain and the shock with the previous $\boldsymbol{\mu}^-$. Mathematically, the estimate for the corrected mean is defined as:

$$\boldsymbol{\mu} = \boldsymbol{\mu}^- + \mathbf{K}(\mathbf{Z} - \mathbf{H}\boldsymbol{\mu}^-)$$

5. Dimensionless Shock

Since the matrices \mathbf{H} and/or $\boldsymbol{\Phi}$ depend on current state estimates and are used to obtain revised state estimates, there is a potential for bad estimates to get worse, and complete loss of track is possible.³³ *Dimensionless shock* can be viewed as a normalized shock value that can be used to determine when the shock is excessively large.³⁴ The dimensionless shock, \mathbf{DS} , is defined as:

$$\mathbf{DS} = \mathbf{S}^T (\mathbf{H}\boldsymbol{\Sigma}^- \mathbf{H}^T + \mathbf{R})^{-1} \mathbf{S}$$

$$\mathbf{S} = \mathbf{Shock} = (\mathbf{Z} - \mathbf{H}\boldsymbol{\mu}^-)$$

In ASW eFusion, the dimensionless shock \mathbf{DS} , statistically known as a Mahalanobis Distance, can become excessive when a new contact report does not meet time and distance feasibility of the previous contact report.³⁵ This could indicate that the new contact report is false or a different target. However, it could also indicate that the previous contact report is false while the new contact report is valid. \mathbf{DS} is a key measurement for contact management and data fusion. If the operator is able to sort and group track data, this would allow the operator to manage the size of the shock values to the system. The effects of this concept are examined in Chapter VII.

³³ Washburn, “A Short Introduction to Kalman Filters.”

³⁴ Kirk, ASW eFusion: Description and User’s Manual (Draft Version), 18–19.

³⁵ Washburn, “A Short Introduction to Kalman Filters.”

B. KALMAN FILTER ALGORITHM

Following some initial estimate for the system state, the Kalman filter recursively updates an estimate of the system state accounting for the passage of time and new measurements shown in Figure 5.

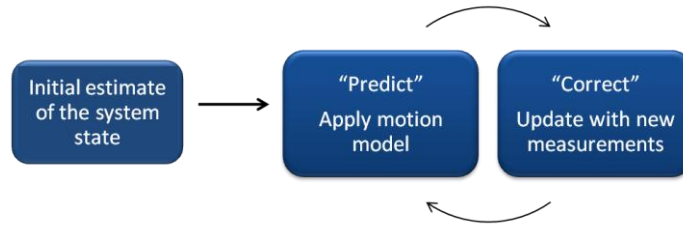


Figure 5. Kalman Filter Algorithm

1. Linear Measurements

When the movement and measurement models are linear functions (i.e., positional data in the form of latitude and longitude) of the system state, the Kalman filter equations for movement and measurement summarized in Figure 6 are used, where I is the *identity matrix*.

<p><u>Movement</u> Project estimate at time t</p> <div style="border: 1px solid black; padding: 10px; width: fit-content; margin: auto;"> $\mu_t^- = \Phi \mu$ $\Sigma_t^- = \Phi \Sigma \Phi^T + Q$ </div>	<p><u>Measurement</u> Correct estimate based on measurement Z at time t</p> <div style="border: 1px solid black; padding: 10px; width: fit-content; margin: auto;"> $K_t = \Sigma_t^- H^T (H \Sigma_t^- H^T + R)^{-1}$ $\mu_t = \mu_t^- + K_t (Z_t - H \mu_t^-)$ $\Sigma_t = (I - K_t H) \Sigma_t^-$ </div>
---	---

Figure 6. Kalman Filter Equations

2. Nonlinear Measurements – Extended Kalman Filter (EKF)

For bearing-only measurements in ASW eFusion, the measured angle is a nonlinear function of the state, requiring that an Extended Kalman Filter (EKF) be used. In this case, the function θ relates the measurements Z to the system states as follows:

$$Z = \theta(X) + V$$

The measurement matrix H now becomes the matrix of first partial derivatives (i.e., the Jacobian) of θ with respect to X . Furthermore, while H is used in calculating both the Kalman gain K and system state's covariance matrix Σ , it is no longer used to calculate the shock. Instead, the nonlinear function itself is used as follows:

$$Shock = Z - \theta(\mu_t^-)$$

III. MANAGING CONTACT REPORTS

A. LIFE CYCLE OF A CONTACT REPORT

In ASW eFusion, the software follows the algorithm illustrated in Figure 7, to estimate a target's position and AOU. To begin estimation of a target's location, when new contact report is entered into the system, ASW eFusion first applies a motion model to project the target's future position. As new measurements are observed, the software then corrects this estimate. Specifically, it discounts contact reports that cannot be feasibly (based on time and distance) correlated with the previous contact.

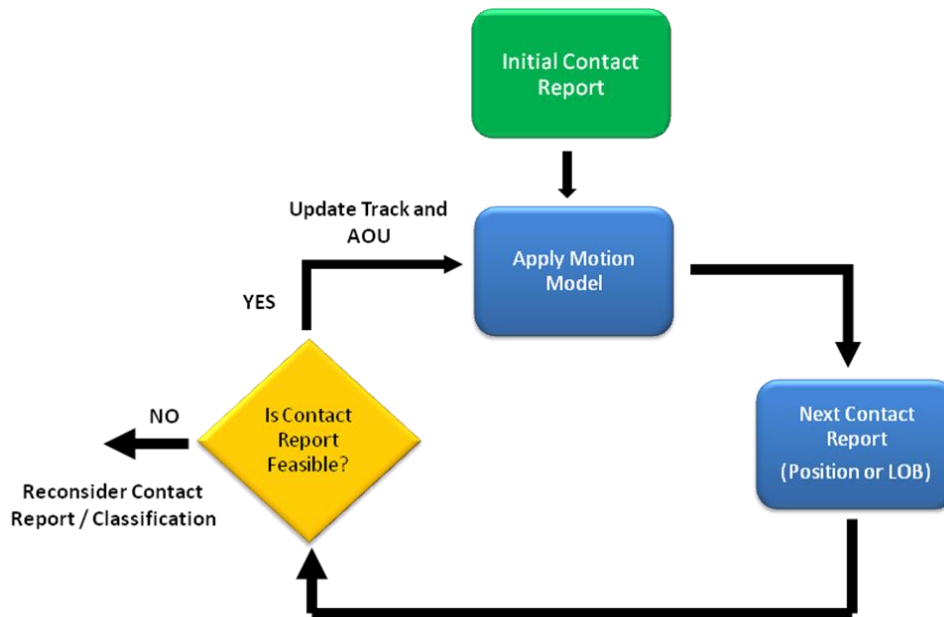


Figure 7. Contact Report Life Cycle

B. AOU GENERATION USING EMBEDDED MOTION MODELS

To track a maneuvering target successfully, the details of the target path should be statistically predictable.³⁶ ASW eFusion allows the user to select one of two options to estimate how targets move and how AOUs grow between measurements. Users can also

³⁶ Paul W. Vebber, "An Examination of Target Tracking in the Antisubmarine Warfare System Evaluation Tool (ASSET)," Naval Postgraduate School Master's Thesis, 1991.

view the estimated tracks and/or AOU's for up to four targets simultaneously. The default option uses the Maneuvering Target Statistical Tracker (MTST), while the second option is based on the concept of furthest-on circles (FOC). Generally, the MTST model is the preferred choice if it is believed that a submarine is on patrol in a confined area, while the FOC option is a better choice if the course and intent of the submarine are unknown.

1. Maneuvering Target Statistical Tracker (MTST)

MTST applies to targets moving freely in a two-dimensional space. The MTST state vector consists of both the two-dimensional and velocity components. Each velocity component is assumed to be an Integrated Ornstein-Uhlenbeck (IOU) process, the simplest normal, stationary process that fluctuates around zero. Conceptually, IOU process produces the velocity distribution of a particle which is undergoing random motion similar to Brownian motion, experiencing random instantaneous accelerations, but whose velocity is damped by a spring-like effect, which constantly accelerates the particle in the direction opposite its velocity at a rate proportional to that velocity.³⁷ While the average velocity is zero in an IOU process, the root-mean-square velocity is not. In addition to specifying the root-mean-square velocity, the *relaxation time* is the time that it usually takes for the velocity to change significantly.³⁸ The default value used within ASW eFusion is two hours within ASW eFusion. Additionally, the boundary of the calculated AOU represents an equiprobability contour that contains the target with some specified probability.³⁹ The default probability is 86.5%, which represents a *two-sigma ellipse*.

2. Furthest-On Circles (FOC)

The alternative option to the MTST model is based upon the concept of furthest-on circles (FOC), where the target is assumed to be moving at constant speed in some unknown but constant direction. Whereas in the case of the MTST model, rate of growth

³⁷ Vebber, "An Examination of Target Tracking in the Antisubmarine Warfare System Evaluation Tool (ASSET)," 18–20

³⁸ Kirk, ASW eFusion: Description and User's Manual (Draft Version).

³⁹ Ibid.

if the AOU increases rapidly at first but then decays over time, the AOU continues to grow exponential when using the furthest-on-circles option.

C. ASW MEASUREMENTS

In ASW eFusion, there are two types of measurements—position measurements and line of bearing (LOB) measurements. Position measurements could be given as latitude and longitude of the target position or a range and bearing from a given position, either a reference point or the reporting unit.

1. Position Measurements

Recall that measurements, \mathbf{Z} , related to the system state according to the measurement model:

$$\mathbf{Z} = \mathbf{H}\mathbf{X} + \mathbf{V}$$

\mathbf{H} is the measurement matrix that describes how the measurements depend on the state. Since positional measurements represent an unbiased estimate of the target position, \mathbf{H} is simply a fixed value, equal to:

$$\mathbf{H} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

2. Line of Bearing (LOB) Measurements

Line of bearing measurements (LOB) includes the reporting unit's position, a bearing to the target, and a bearing error (given as two standard deviations). The geometry for a LOB measurement from a reference unit at (x_1, y_1) is given in Figure 8.

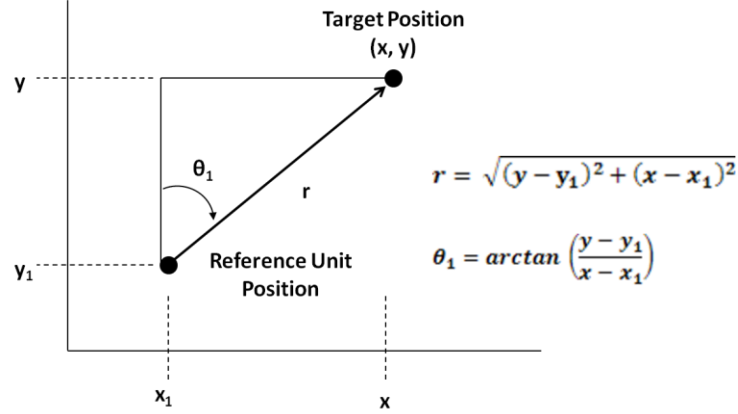


Figure 8. Geometry for a LOB contact report

Since the measured angle θ_1 is a nonlinear function of the state, an extended Kalman filter (EKF) must be used. Recall that the nonlinear function θ relates the measured angle to the system state as follows:

$$\mathbf{Z} = \theta(\mathbf{X}) + \mathbf{V}$$

For an EKF, the matrix \mathbf{H} becomes the Jacobian of the nonlinear function as shown:

$$\mathbf{H} = \begin{bmatrix} \frac{\partial \theta}{\partial x} & \frac{\partial \theta}{\partial y} & 0 & 0 \end{bmatrix}$$

$$\frac{\partial \theta}{\partial x} = \frac{\cos(\theta)}{r} = \frac{y - y_1}{(y - y_1)^2 + (x - x_1)^2}$$

$$\frac{\partial \theta}{\partial y} = \frac{-\sin(\theta)}{r} = \frac{-(x - x_1)}{(y - y_1)^2 + (x - x_1)^2}$$

Since \mathbf{H} is now a function of the system state, it's necessary to solve for the estimated target position through iteration.⁴⁰ Usually, if a LOB contact report can be reasonably correlated with a previous contact, given time/distance consideration, the solution quickly converges.

⁴⁰ Kirk, ASW eFusion: Description and User's Manual (Draft Version), 28.

D. CORRELATING CONTACTS

When the solution for positional or LOB measurements do not converge at least approximately, this is known as a divergent solution. This happens when the new contact cannot be reasonably correlated with the previous contact report (see Chapter II.A.5 for discussion of dimensionless shock *DS*). Divergence can be caused by a poor initial target estimate or a series of false contact reports that are inputted as true.⁴¹ In ASW eFusion, if the new contact report is not feasible from a time/distance perspective, the user will be presented with a warning displayed in Figure 9.

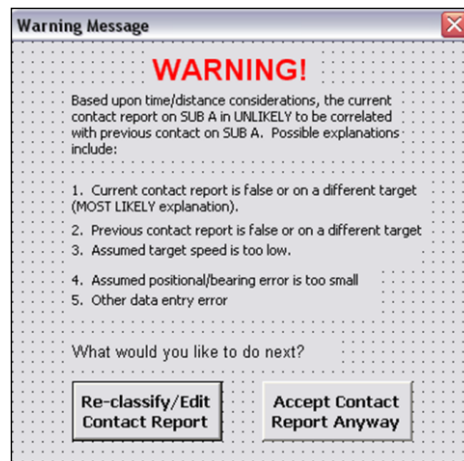


Figure 9. Contact Warning Message

There are many reasons why a new contact report may not be correlated with the previous contact report. Usually, it will be due to the new contact report being false or on a different target. In this case, the operator can select “Re-classify/Edit Contact Report” to modify the contact entry data. Other possibilities could be that this new contact report is accurate and the previous contact report was not. In this instance, the user should select “Accept Contact Report Anyway” and then edit the previous contact report in the program’s “Contact_Log” worksheet.

⁴¹ Kirk, ASW eFusion: Description and User’s Manual (Draft Version), 35.

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IV. APPLICATION FOR THEATER ASW

Commander, Anti-Submarine Warfare Force U.S. Third Fleet/Commander, Task Force THREE FOUR (CTF-34), engaged in daily theater ASW operations, recognized the practicality of ASW eFusion and began investigating the potential use of the software for theater ASW operations. The mission of CTF-34 is to provide operational and tactical command and control of theater anti-submarine warfare (TASW) and reconnaissance forces in the THIRD Fleet Area of Responsibility (AOR). Additionally, CTF-34 provides theater anti-submarine warfare training to deploying naval forces and administrative oversight for Pacific Fleet Integrated Undersea Surveillance System (IUSS) assets.⁴²

1. The Issue

According to U.S. Navy Commander George Wright, CTF-34 Training and Plans Officer, ASW eFusion could be set up on a Windows-based PC as a standalone system on the Tactical Watch Floor or in the Mission Planning Cell (MPC).⁴³ On the watch floor, the software's ability to estimate target motion and generate AOUs could complement larger theater ASW systems like USW-DSS to provide real-time assistance to the TASW Commander. Additionally, screen captures of ASW eFusion's tactical plot could be used for daily flag and warfare commander briefings. In the MPC, the program's playback feature could help mission planners and data analysts re-engineer past ASW missions by comparing the effects of submarine truth tracks against tracks previously generated by other theater ASW sensors. The problem with this process is that the program routinely exhibited several system timing problems when attempting to insert time-late observation data from submarines.

In November 2010, after learning of the author's follow-on fleet assignment to CTF-34, CDR Wright requested the author's assistance in investigating ASW eFusion's

⁴² U.S. Navy (n.d.). *Commander, Submarine Force U.S. Pacific Fleet*. Retrieved May 2, 2011, from Commander, Anti-Submarine Warfare Force, U.S. Third Fleet (CTF-34) Official Site: <http://www.csp.navy.mil/CTF-34/index.shtml>.

⁴³ George C. Wright, 2011, private communication.

problematic time-late processing issue.⁴⁴ He further explained that, many of the contact reports and messages CTF-34 receives from submarines are routinely time-late due to the limited communication windows a submarine has during ASW operations. In order for ASW eFusion to be of any tactical utility to the fleet, this program must to be able to properly process time-late target positioning data.⁴⁵

The remaining chapters examine ASW eFusion's problematic ability to handle time-late reports, prescribe working solutions, and investigate methods to improve the program's user interface for use on the tactical watch floor.

⁴⁴ Commander George C. Wright (USN) is a graduate of NPS and the command sponsor for author's next operational fleet assignment.

⁴⁵ Wright, 2011, private communication.

V. TESTING AND ANALYSIS

A. APPROACH

For technical assistance with ASW eFusion in support of this thesis, the author attempted to contact Dr. Kevin M. Kirk, the program's developer, at the Center for Naval Analyses (CNA) Corporation in Arlington, Virginia. In the past, Dr. Kirk served as a CNA field representative to the Tactical Training Group Pacific (TACTRAGRUPAC) in San Diego, California. Unfortunately, according to the CNA Field Office, Dr. Kirk concluded his employment with the company in late 2005. In addition, both CNA and TACTRAGRUPAC did not have any forwarding contact information for Dr. Kirk on record. As a result, the developer was unreachable for comment.

Next, the author contacted the CNA Document Control and Distribution Section to try and obtain all supporting documentation of the ASW eFusion software. Surprisingly, the author learned that no documentation or software for ASW eFusion existed on file. According to the CNA Document Control representative, "it is possible that Dr. Kirk never completed the project through publication."⁴⁶ The only available documentation for ASW eFusion is a draft version of the user's manual entitled "*ASW eFusion: Description and User's Manual (2005)*." The author also obtained an Excel workbook for ASW eFusion (Version 1.4). The workbook was password protected by Dr. Kirk, which made the computer code inaccessible for study. However, as an essential resource for this research, the author obtained a modifiable version of the software, ASW eFusion (Beta Version, January 2005) from Professor Washburn. This workbook enabled the author to gain a firm understanding of ASW eFusion's Microsoft Visual Basic for Applications (VBA) computer code and more importantly model the time-late issues identified by CTF-34.

⁴⁶ CNA Document Control representative, February 2011, private conversation.

1. Comparing ASW eFusion (Version 1.4) and ASW eFusion (Beta)

While nearly all computing aspects between ASW eFusion (Version 1.4) and ASW eFusion (Beta) remain unchanged, the main feature difference was the addition of mapping display controls in ASW eFusion (Version 1.4). Specifically, with ASW eFusion (Version 1.4) user-friendly mapping controls were added to the “Contact_Plot” worksheet. This enhancement allowed the user to quickly shift the “Contact_Plot” display, by zooming in/out or moving the map left/right/up/down with the click of a button. On the other hand, the ASW eFusion (Beta) version does not have this feature. Instead, the operator accomplishes mapping functions by manually entering grid boundaries for geographic areas of interest or areas of operation.

A comparison test of both versions of ASW eFusion was conducted to determine if the program’s produced equivalent outputs when given the same “Contact_Log” as input shown in Figure 10.

Enter Contact Report

Instructions to add/edit contact reports:

Add contact reports by clicking on the "Enter Contact Report" button to the left or by manually entering contact information into the spreadsheet below. When manually entering/modifying contact reports, be careful to enter data in the proper format to ensure all data is properly plotted. Also, note that no contact reports will be plotted after the first blank line.

Contact DTG	Classification / Track ID	Local Time		Source Unit	Ref	Source Latitude	Source Longitude	Sensor	Confidence	Contact BRG (deg)	Contact Rng (kyds)	Contact Lat	Contact Lon	Contact CRS/SPD
		Date	Time											
1105221640Z	TARGET A	22-May	9:00	S-3B				VISUAL	POSS LO1			32-00N	121-00W	deg / kts
1105221000Z	TARGET A	22-May	10:00	S-3B				RADAR	POSS LO2			32-00N	120-50W	deg / kts
1105221100Z	TARGET A	22-May	11:00	P-3C				RADAR	POSS H3			32-00N	120-40W	deg / kts
1105221130Z	TARGET A	22-May	11:30	SSN1				ACT SONAR	CERTSUB			31-58N	120-55W	deg / kts
1105221230Z	TARGET A	22-May	12:30	P-3C				PASS BUOY	POSS LO2			32-00N	120-25W	deg / kts
1105221300Z	TARGET A	22-May	13:00	BAMS				RADAR	PROBSUB			32-01N	120-20W	deg / kts
1105221500Z	TARGET A	22-May	15:00	SSN1				ACT SONAR	PROBSUB			32-01N	119-30W	deg / kts
1105221530Z	TARGET A	22-May	15:30	BAMS				RADAR	CERTSUB			32-00N	119-27W	deg / kts
1105221600Z	TARGET A	22-May	16:00	FFG1				TOWED ARRAY	PROBSUB			32-00N	119-22W	deg / kts
1105221230Z	TARGET A	22-May	12:30	DDG1				PAS SONAR	POSS LO1			32-01N	120-40W	deg / kts

Figure 10. Notional contact log

The operator entered each line item in the contact log using the “Enter Contact Report” button on the “Contact_Log” worksheet. Functionally, both versions exhibited the identical behaviors in its ability to plot and display the contacts. For example, if a contact did not meet time and distance feasibility checks, the operator received the “Contact Warning” message alerting him to correct or accept the entry shown earlier in Figure 9. After all the contacts were entered, the resulting estimated target location and AOU properties were examined. Using the contact log in Figure 10 as input, both programs estimated the TARGET A’s location at “32-00N/119-24W,” patrolling with

course of 094 degrees and four knots. In addition, both programs generated an initial AOU size of 32 square nautical miles. The “Contact_Plot” and TARGET A’s track details can be found in Figure 11.

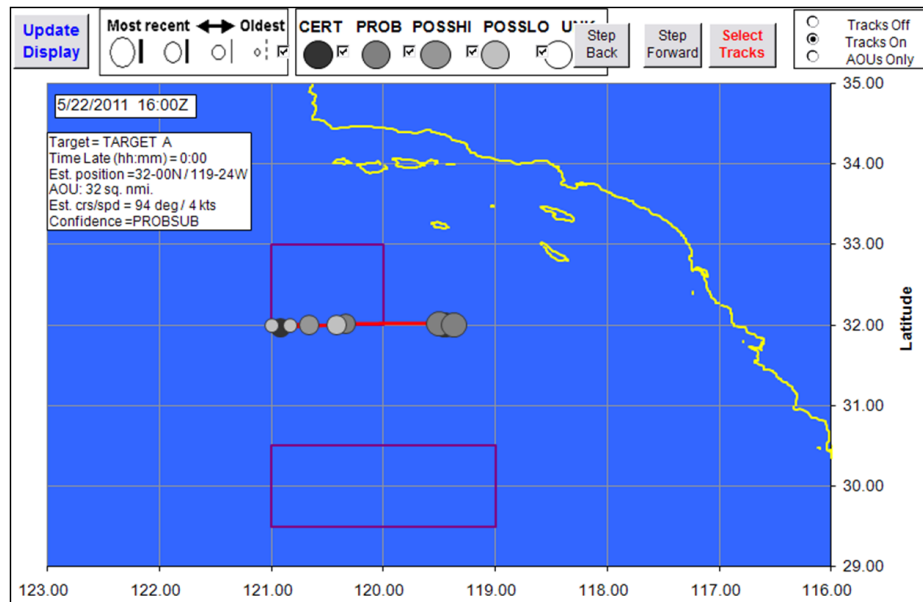


Figure 11. Plot of notional contact log

This test demonstrated that, both versions of the software possessed matching abilities to manage, organize, fuse, and display contact data. Further, the test established that the core Kalman filtering algorithms and subroutines were not changed between versions and operating as designed. Of note, the confounding system timing issues identified by CTF-34 existed in both ASW eFusion (Beta) and ASW eFusion (Version 1.4) and is described in Section B of this chapter.

2. Comparison of ASW eFusion and PCTracker

Since ASW eFusion’s (Beta) computer code was accessible by the author, an additional test was conducted to determine if ASW eFusion’s Kalman filtering algorithms produced feasible estimates for target location and AOU. Using the same notional contact log shown in Figure 10, ASW eFusion’s (Beta) outputs were compared against “PCTracker.” PCTracker is an Excel-based tracking tool developed by Professor Washburn and is synonymous in function to Mann’s LosCon tactical decision aid

described earlier. Recall that Dr. Kirk to utilized LosCon's (i.e., PCTracker) core Kalman filtering algorithms and subroutines in the development of ASW eFusion.

	ASW eFusion (Beta)	PC Tracker
Estimated Target Position	32-00N/119-24W	31-59.986N/119-22.783
AOU major axis (nm)	6.3589	6.9992
AOU minor axis (nm)	6.3589	6.9992
AOU orientation (degrees)	135	135

Table 1. Estimated position and AOU comparison

Viewing the data results in Table 1, both programs discernibly generated closely related estimates for position data and AOU parameters. This further demonstrated to the author that ASW eFusion's Kalman filtering algorithms and were indeed functioning properly.

B. DUPLICATING THE INTERFACE ISSUES

To replicate the issues that CTF-34 encountered, a notional ASW mission scenario was developed to examine the re-engineering application of ASW eFusion. Specifically, this test modeled the process of adding submarine truth tracks to target generated track solutions from a past ASW mission. In the test scenario, the tracking events of a notional target "SUB A" took place on April 3, 2011 and lasted seven hours in duration from 1700 to 2400 hours. The "Contact_Log" for the mission consisted of several positional observations from various air and surface platforms as illustrated in Figure 12.

<div> <div>Enter Contact Report</div> <div> Instructions to add/edit contact reports: Add contact reports by clicking on the "Enter Contact Report" button to the left or by manually entering contact information into the spreadsheet below. When manually entering/modifying contact reports, be careful to enter data in the proper format to ensure all data is properly plotted. Also, note that no contact reports will be plotted after the first blank line. </div> </div>													
		Local Time											
Contact DTG	Classification / Track ID	Contact Date	Contact Time	Source Unit	Ref	Source Latitude	Source Longitude	Sensor	Confidence	Contact BRG (deg)	Contact RNG (kyds)	Contact Lat	Contact Lon
1104040329Z	SUB A	3-Apr	17:00	S-3B				RADAR	POSS L01			32-00N	121-00W
1104040333Z	SUB A	3-Apr	18:00	S-3B				VISUAL	POSS L02			32-00N	120-50W
1104040200Z	SUB A	3-Apr	19:00	P-3C				RADAR	POSS H3			32-00N	120-40W
1104040230Z	SUB A	3-Apr	20:30	P-3C				PASS BUOY	POSS L02			32-00N	120-25W
1104040349Z	SUB A	3-Apr	19:20	DDG1				ACT SONAR	CERTSUB			31-58N	120-55W
1104040330Z	SUB A	3-Apr	20:30	DDG1				PASS SONAR	POSS L01			32-01N	120-40W
1104040415Z	SUB A	3-Apr	21:00	BAMS				RADAR	PROBSUB			32-01N	120-20W
1104040403Z	SUB A	3-Apr	23:00	FFG1				ACT SONAR	PROBSUB			32-01N	119-30W
1104031948Z	SUB A	3-Apr	23:30	BAMS				RADAR	CERTSUB			32-00N	119-27W

Figure 12. Mission contact log

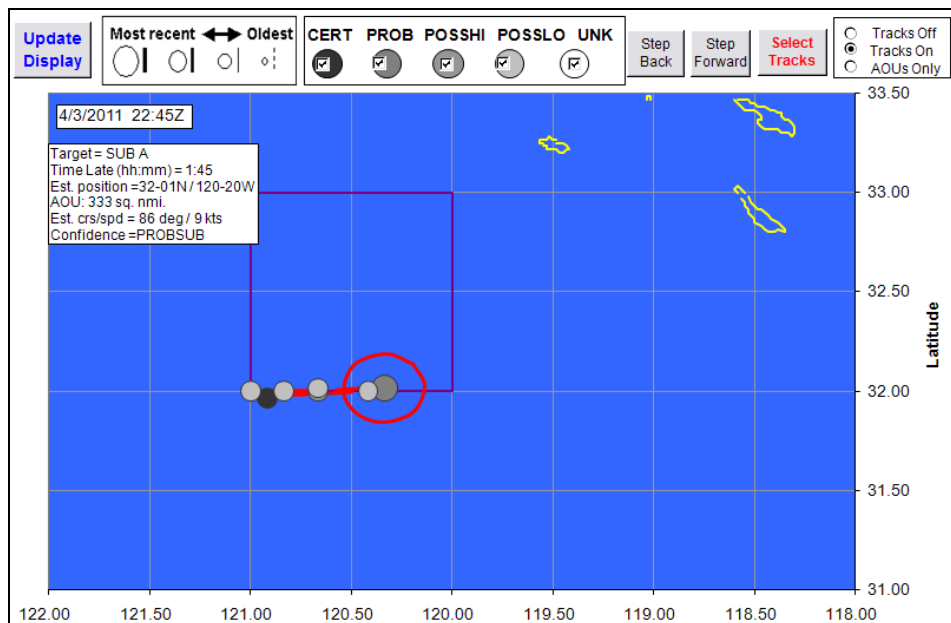


Figure 13. Notional ASW Mission Scenario

Figure 13 graphically depicts ASW eFusion’s tracking solution and AOU for “SUB A.” In this example, “SUB A” has been estimated to be at 32-01N/120-20W transiting east at nine knots with an AOU ellipse of 333 square nautical miles. From Figure 13, also take note of the mission time and target information at the top left corner of the display. The current mission day is 4/3/11 with mission time 22:45 Zulu. This date and time value is also reflected on the “Program Settings” page shown in Figure 14.

Program Settings:		Reset Default Values
Time		
Zulu correction:	0	hours
Current time (local):	4/3/2011 22:45	Local
Time offset:	0.00	days
Time start (replay mode):	1/1/2005 6:00	Local
Time end (replay mode):	1/2/2005 6:00	Local
Time step (replay mode):	15	minutes

Figure 14. Program Settings – current mission time

The track information box just below the mission clock in Figure 13, also details the target's name, estimated position, course and speed, and confidence level of the observation. Notice that the no new reports have been observed for one hour and 45 minutes or "1:45 time-late." This is represented graphically by the red 333 square nautical mile AOU ellipse surrounding the last position of the target.

To examine the effects of submarine truth tracks on the data, the operator added a new target observation from a friendly submarine "SSN1" shown in Figure 15. Note, a contact time of "21:14Z" and location of "32-00N/120-22W" was deliberately used to give the target feasible values for time and distance considerations.

ASW Contact Entry

ASW Contact Data Entry Form

Date: 4/3/11 Entry Date: 05/15/11
Time: 21:14 ☒ Zulu ☐ Local Entry Time: 21:14

Reference/Source Information **Contact Information**

Reporting unit: SSN1 ☒ LAT / LON ☐ BRG / RNG
Reference pt:
Latitude: 00-00N Latitude: 32-00N Bearing: deg
Longitude: 000-00W Longitude: 120-22W Range: yds
Sensor: ACT SONAR Pos error: 2 nmi Brg error: 2 deg

Amplifying information (e.g., target freq, ES data, intentions, etc.):

Contact Course: degrees
Contact Speed: knots
Confidence: POSS HI3
Classification/Track ID: SUB A

Figure 15. Notional submarine contact from reporting unit "SSN1"

Once the operator selected the "OK" button, the software exhibited several unexpected outcomes. Specifically, adding new (i.e., time-late) sensor data to a previously computed track solution, caused the application to unpredictably advance the system's current time (i.e., mission time) to the real world current time as shown in Figure 16. Note, 5/15/2011 21:42 reflected the actual time on the host computer when the operator pressed the "OK" button.

Program Settings:		Reset Default Values
Time	Zulu correction:	0 hours
	Current time (local):	5/15/2011 21:42 Local
	Time offset:	0.00 days
	Time start (replay mode):	1/1/2005 6:00 Local
	Time end (replay mode):	1/2/2005 6:00 Local
	Time step (replay mode):	15 minutes

Figure 16. Unexpected mission time change

Additionally, all the contact reports in the “Contact_Log” were processed up through the current local time, in this case “5/15/2011 21:42.” Since the system time was unpredictably advanced by a month and 12 days, Figure 17 shows, the resulting AOU ellipse increased in size from the 333 to 227,533 square nautical miles as displayed in the in the target track information box. Note the actual AOU is not visible due to its excessive size.

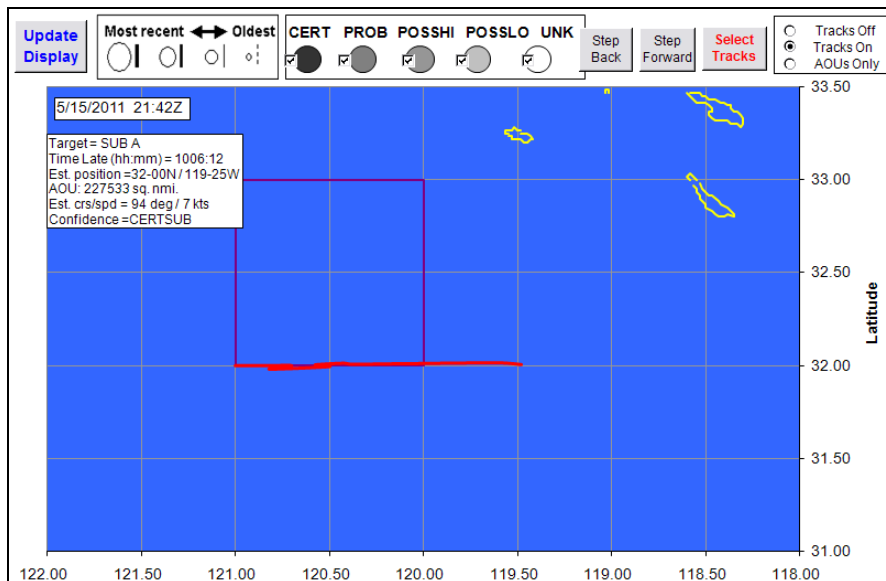


Figure 17. Contact_Plot after adding time-late report

ASW eFusion also enables the user to define “cutoff” times, which allows the user to differentiate how time-late data are displayed on the “Contact_Plot” shown in Figure 18.

Cutoff times for displaying contact data:		
Time #1:	2	hours
Time #2:	6	hours
Time #3:	12	hours
Don't display data older than:	24	hours




Figure 18. Display cutoff times

The target track information box in Figure 17 shows that the elapsed time between the last reports in the “Contact_Log” changed from “1:45” time-late to one thousand six hours and twelve minutes or “1006:12” time-late. This clearly exceeded the system’s default 24-hour cutoff time setting displayed in Figure 18. As a result, all the contacts were cleared from the “Contact_Plot.” Figure 17 represents the resulting degraded “Contact_Plot,” the operator is left to contend with. Of note, this outcome occurred both when a new contact report met time and distance feasibility and when it did not.

VI. PROPOSED SOLUTIONS

A. OPERATOR WORKAROUNDS

At the user level, the operator can restore the “Contact_Plot” to its previous state (before the adding time-late contact) by using the “Step Back” time function or manually resetting the “Current system time” to the desired mission time in the “Program Settings” page.

1. Manual “Step Back” Method

This method involves the use of the “Step Back” button on the “Contact_Plot” to manually step the “Contact_Plot” display back in time. In ASW eFusion, the “Time Step” setting on the “Program Settings” page will step the “Contact_Plot” forward or back in time by the amount specified in the “Time Step” setting (in minutes). To get the “Contact_Plot” display back to the mission time window, manually press the “Step Back” button as many times needed by step the system clock back in time. For example, using a “Time Step” setting of 30 minutes (the default), if the operator wanted to reverse the “Contact_Plot” back in time by six hours, this would be accomplished by depressing the “Step Back” button 12 times. Note, it is recommended to use this procedure only when the display needs to be adjusted in hourly segments. If the “Contact_Plot” display needed to be set back several days, weeks, or even months, this method would become very cumbersome and not efficient. A better procedure to consider is the “Mission Clock Reset” Method.

2. “Mission Clock Reset” Method

The “Mission Clock Reset” method requires the operator to change the “Current system time” setting on the “Program Settings” page to the desired mission time. Intuitively, the user would expect that pressing “Update Display” button on the “Contact_Plot” would update the display to the new specified time. Instead, after the user presses the “Update Display” button it erroneously re-inserts the host computer’s

current system time back into the “Current system time.” In addition, the “Contact_Plot” updates inadvertently updates to the host computer’s current time, not the desired mission time.

To remedy this, the operator must select the either “Step Forward” or “Step Back” button after entering the desired mission time “Program Settings” page. Note use of the “Step Forward” or “Step Back” button in this fashion is not documented in the user’s manual. After performing those procedures, the time on the “Contact_Plot” display correctly resets to the user specified mission time. The problem with this fix is that it may be short lived. For example, if the operator chooses to add another (i.e., time-late) contact entry into the system, then the troubles with the system time settings repeats itself all over again. That is, the mission time advances to the host computer’s current time and the resulting “Contact_Plot” displays a time-lapsed progression of the tactical situation. The preferred method is to modify the ASW eFusion computer code directly.

B. PROPOSED CODE MODIFICATION

After tracing the “system time” issue through the VBA computer code, the source of a logic problem was found within the *OKEntry_Click* subroutine. The troublesome lines of code are depicted in Figure 19. The entire *OKEntry_Click* subroutine can be found in the Appendix.

```
TempTime = (Now() + Worksheets("Settings").Range("Offset").Value)

If (LogRowNum = 0) And (ContactTime <= TempTime) Then
    Call CurrentDisplay
Else
    Worksheets("Settings").Range("CurrTime").Value = ContactTime
    Call startUpdate
End If
```

Figure 19. Problematic lines of computer code

From the VBA code in Figure 19, “ContactTime” is defined as the observation time of the new contact report. Additionally, “TempTime” represents the host computer’s current system date and time plus the user-defined offset value for Zulu time. “LogRowNum” is set equal to zero and does not change within the subroutine.

Following the logic as written, when conducting analysis of a past event, a new contact report's "ContactTime" will always be less than "TempTime" which, again, is the host computer's current system time. Therefore, the Boolean logic for the IF statement will always return a value of "true." This, in turn, calls the *CurrentDisplay* subroutine, which inadvertently updates the "Current time" setting to the host computer's current time and displays a time-lapsed progression of the track data on the "Contact_Plot."

A workable fix for this issue is to set the current system time on the "Program Settings" page equal to "ContactTime" of the new observation. This will prevent the program's mission clock from inadvertently updating to the computer's current system date and time. Figure 20 illustrates the modifications to the affected computer code. The green highlighted text represents code that was commented out. The lines in black represent the new lines of executable code. It is also recommended that the new computer code be reviewed by a qualified VBA programmer for correctness.

```
'TempTime = (Now() + Worksheets("Settings").Range("Offset").Value)

'If (LogRowNum = 0) And (ContactTime <= TempTime) Then
'Call CurrentDisplay
'Else
    Worksheets("Settings").Range("CurrTime").Value = ContactTime
    Call startUpdate
'End If
```

Figure 20. Proposed new lines of code

The new code was tested using the notional contact log shown in Figure 12 and by adding the same contact report shown in Figure 15. After adding several new or time-late targeting reports to the database, the program correctly processed and displayed the track data with no issue. Additionally, the system time on the "Program Settings" page properly updated with each new contact report. With the code modifications in place, this demonstrated that ASW eFusion could properly handle post positional data for re-engineering purposes.

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VII. RECOMMENDATIONS FOR IMPROVEMENT

While ASW eFusion can be viewed as an improvement to the many of the manually intensive watchstanding activities, its functionality and usefulness could be further developed to make it a more effective tool for the tactical watchstander.

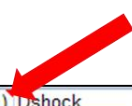
A. DATA SORTING

Recall that ASW eFusion warns the operator when a new contact report does not meet time and distance feasibility. This warning is based on the shock value to the system. Specifically, when the dimensionless shock *DS* value exceeds a value of ten (see Appendix), the user is issued the warning message shown in Figure 9. This indicates that the new contact is either false or on a different target. Although a new report may not meet time and distance feasibility estimates, the ASWO may determine that it is a valid report and need to check it against the target's track history. For instances like this, ASW eFusion, currently does not possess a data sorting ability to allow the user to selectively group or ignore a set of historical contacts. This can only be done manually by editing or deleting previous track entries in the "Contact_Log."⁴⁷ An improvement to the software would be to add a toggle switch to the "Contact_Log" worksheet. LosCon, ASW eFusion's predecessor, had this capability shown in Figure 21.

In LosCon, the toggle switch enabled the operator to selectively include or ignore contacts allowing him to visually understand each contact reports' effect on the AOU.⁴⁸ The operator enters a '1' for a bearing measurement, '2' for a position measurement, or a '0' to skip a measurement without erasing it from the worksheet. Within ASW eFusion, if a contact report exceeds time and distance feasibility estimates, by implementing a toggle switch of this type, the operator will have the flexibility to examine the new contact and check its validity against existing tracks in the "Contact_Log."

⁴⁷ Kirk, ASW eFusion: Description and User's Manual (Draft Version), 28–29.

⁴⁸ Ibid, 13.



Source	ID	lat (deg)	lat(min)	lon(deg)	lon(min)	y(nm)	x(nm)	Brg(d)	Sigma	Target#	Time (hrs)	Include(0/1)	Dshock
S-3B	1	32	0	121	0	0	0		2	1	0	2	0
S-3B	2	32	0	120	50	0	8.48		2	1	1	2	1.572719602
P-3C	3	32	0	120	40	0	17		2	1	2	2	1.478383
SSN1	4	31	58	120	55	-2	4.24		2	1	2.5	2	10.91964879
P-3C	5	32	0	120	25	0	29.7		2	1	3.5	2	20.12232657
DDG1	6	32	1	120	40	1	17		2	1	3.5	0	
BAMS	7	32	1	120	20	1	33.9		2	1	4	2	0.463889007
SSN1	8	32	1	119	30	1	76.3		2	1	6	2	18.70974451
BAMS	9	32	0	119	27	0	78.9		2	1	6.5	2	0.087924114
FFG1	10	32	0	119	22	0	83.1		2	1	7	2	0.470169196

Figure 21. LosCon contact entry worksheet

B. WEIGHTED CONFIDENCE LEVELS FOR CORRELATION

When the operator enters a new contact into the “Contact_Log” in ASW eFusion, he can assign a confidence level to that report. The values range from CERTSUB, PROBSUB, POSSUB HI 1/2, POSSUB LO 1/2, and NONSUB. After examination of the program’s code, it is evident that these confidence levels are utilized primarily for display purposes and not correlation. Specifically, the contact’s symbol on the “Contact_Plot” is displayed to the user in varying intensities of black and gray. If the user selects CERTSUB, a black colored dot is displayed on the “Contact_Plot.” Similarly, if the operator selects PROBSUB, a dark gray dot is plotted. Lighter shaded gray dots are used for POSSUB and below.

An improved approach would be to apply weighting to the confidence levels of a contact report. For example, CERTSUB = 1.00, PROBSUB = 0.85, POSSUB HI = 0.65, POSSUB LO = 0.50, and NONSUB = 0.01. Similar in concept to Dshock for track quality and feasibility, these weighted values could be used by ASW eFusion to determine likelihood of the contact actually being a threat submarine. For example, if a new contact report had a confidence level of PROBSUB or higher, the operator could use the toggle switch described earlier skip previous contact reports and include the current contact report for the first observation in the target’s track history. In addition, if the sensor determines the contact report to be less than POSSUB LO or NONSUB, the toggle switch could be used skip the report. The intent for this method is to give the operator additional flexibility to sort and correlate track data.

C. STANDARD NAVY ICONS

ASW eFusion currently uses basic symbols such circles and lines to represent or positional or bearing data shown in Figure 22.

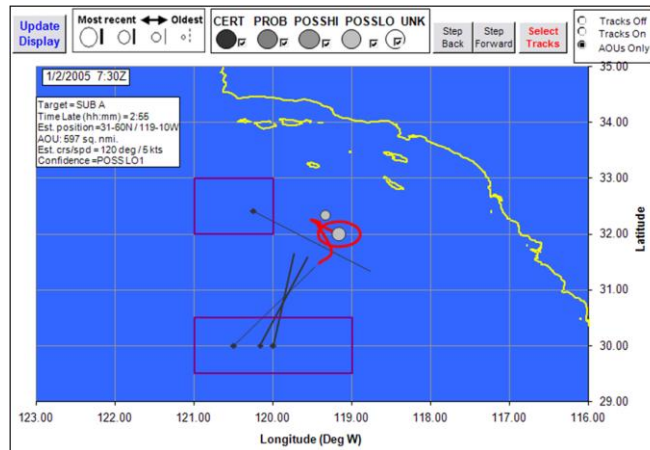


Figure 22. ASW eFusion Contact_Plot

Contact reports are displayed on the “Contact_Plot” using colored dots to represent current target location. Visually, the dots get smaller as time increases indicating the “age” of the data (bigger dots are more recent than smaller dots). Intuitively, this helps the operator discern the timeliness of a contact. However, over time, as multiple observations and/or multiple targets are displayed this tends clutter the plot with numerous random sized dots. An improvement could be made to display track data using with standard naval tactical display system (NTDS) symbology to represent ships, submarines, and aircraft shown in Figure 23. This upgrade provides familiar symbology for the watchstander, by further standardizing it for use on a tactical watchfloor.

Hostile Unknown Friend			Hostile Unknown Friend		
Surface			Air Group		
Sub			Surface Group		
Plane			Sub Group		
Carrier			SAM		
Helicopter			Communications		
Missile			Minefield		
Torpedo			POL		
Passive Sonobouy			Port		
Active Sonobouy			Runway		
Airbase			Structure		
Base			Target		

Figure 23. Naval Tactical Display System (NTDS) Symbol Legend

VIII. CONCLUSION

ASW remains an art.⁴⁹ For successful theater ASW and strike group operations, it is essential that the location of a submerged threat is known at least approximately at all times. This can be achieved through persistent ISR and the proactive management of contact track and sensor data. In its present form, ASW eFusion can support the ASW commander to better manage uncertainty and ultimately make better tactical decisions. While ASW eFusion can simplify and automate many traditional watchstanding duties, it is also recommended to utilize it as a complement and not a substitute, to the manual plot and log.

This thesis has identified and examined a problematic timing issue with ASW eFusion's ability to process time-late reports and presented several solutions to fix the issue. The preferred solution involved implementation of a software patch to remedy the program's subroutine logic for adding new contact reports. With this solution in place, ASW eFusion's utility could be expanded to support post-event analysis by allowing the operator to compare submarine truth tracks against historical track solutions generated by other ASW platforms and sensors.

In addition, if given the funding to acquire a professional VBA programmer, ASW eFusion's software should also be re-examined to consider several functional upgrades. The first improvement involved the addition of a user toggle switch on the "Contact_Log" worksheet to enable contact data sorting and grouping. For contact correlation, the second improvement described the contact confidence level weighting scheme for track management. The last option described the utilization of Naval Tactical Display System (NTDS) symbology to standardize ASW eFusion's contact plot symbology for use on a tactical watchfloor. Given these essential upgrades, ASW eFusion could become a more effective tool for the ASW tactical watchstander or

⁴⁹ Mann, "ASW Fusion on a PC," 11.

mission planner. Lastly, consideration should be also given to using ASW eFusion's ability to estimate target location and AOU as inputs to other large-scale tactical systems like USW-DSS, GCCS-M, or PC-IMAT.

With the fixes identified in this research, CTF-34 and other prospective fleet users can benefit from ASW eFusion's improved functionality. Specifically, the program's enhancements can aid tactical watchstanders in support of real-time ASW operations, as well as, help the mission planner re-engineer significant ASW events in the past. To that end, ASW eFusion further equips the ASW commander and his staff, with the tools necessary for achieving maritime domain awareness and enabling successful ASW operations.

APPENDIX

A. OKENTRY_CLICK SUBROUTINE

```
Dim Sheet1 As Worksheet
Dim PassTest As Boolean
Dim Blank As Boolean
Dim EmptyCell As Boolean
Dim i, LogRowNum As Integer
Dim j As Integer
Dim result As Range

'Check for errors
PassTest = True
If ContactEntry.Unit_Lat <> "" Then
    Call LatLonCheck(ContactEntry.Unit_Lat, PassTest, "LAT")
End If
If (PassTest) And (ContactEntry.Unit_Lon <> "") Then
    Call LatLonCheck(ContactEntry.Unit_Lon, PassTest, "LON")
End If
If (PassTest) And (ContactEntry.Cont_Lat <> "") Then
    Call LatLonCheck(ContactEntry.Cont_Lat, PassTest, "LAT")
End If
If (PassTest) And (ContactEntry.Cont_Lon <> "") Then
    Call LatLonCheck(ContactEntry.Cont_Lon, PassTest, "LON")
End If

If (PassTest) And (ContactEntry.Date_contact <> "") Then
    Call DateCheck(ContactEntry.Date_contact, PassTest)
End If
If (PassTest) And (ContactEntry.Date_entry <> "") Then
    Call DateCheck(ContactEntry.Date_entry, PassTest)
End If
If (PassTest) And (ContactEntry.Time_contact <> "") Then
    Call TimeCheck(ContactEntry.Time_contact, PassTest)
End If
If (PassTest) And (ContactEntry.Time_entry <> "") Then
    Call TimeCheck(ContactEntry.Time_entry, PassTest)
End If
If (PassTest) And (ContactEntry.Rng <> "") Then
    If (ContactEntry.Rng < 0) Then
        PassTest = False
        MsgBox "Error! Make correction to range."
    End If
End If
```

```

End If
If (PassTest) And (ContactEntry.Brg <> "") Then
    If (ContactEntry.Brg < 0) Or (ContactEntry.Brg > 360) Then
        PassTest = False
        MsgBox "Error! Make correction to bearing."
    End If
End If

If (PassTest) And (ContactEntry.PosError <= 0) Then
    PassTest = False
    MsgBox "Error! Positional error must be greater than 0."
End If

If (PassTest) And (ContactEntry.BrgError <= 0) Then
    PassTest = False
    MsgBox "Error! Line-of bearing error must be greater than 0."
End If

LogRowNum = ContactEntry.LogRow.Value

If PassTest Then

'If new contact, find last row in contact log
    Blank = False
    If (LogRowNum = 0) Then
        i = 6
        Do While Not (Blank)
            EmptyCell = True
            j = 1
            Do While ((EmptyCell) And j <= 18)
                Temp = Worksheets("Contact_Log").Cells(i, j).Value
                If Temp <> "" Then
                    i = i + 1
                    EmptyCell = False
                ElseIf j = 18 Then
                    Blank = True
                    j = j + 1
                Else
                    j = j + 1
                End If
            Loop
        Loop
        nLast = i
    Else
        i = LogRowNum
    End If

```

```

End If
nrow = i
If ((ContactEntry.Date_contact) <> "") And ((ContactEntry.Time_contact) <> "") Then

    Temp1 = DateValue(ContactEntry.Date_contact)
    Temp2 = TimeValue(ContactEntry.Time_contact)

    If ContactEntry.LocalOption = True Then
        Temp3 = ((Worksheets("Settings").Range("ZuluCorr").Value) / 24)
        ZDateTime = Temp1 + Temp2 + Temp3
    Else
        ZDateTime = Temp1 + Temp2
    End If
    Temp1 = Right(Str((Year(ZDateTime))), 2)
    Temp2 = Trim(Str(Month(ZDateTime)))
    If Len(Temp2) = 1 Then
        Temp2 = "0" + Temp2
    End If
    Temp3 = Trim(Str(Day(ZDateTime)))
    If Len(Temp3) = 1 Then
        Temp3 = "0" + Temp3
    End If
    Temp4 = Trim(Str(Hour(ZDateTime)))
    If Len(Temp4) = 1 Then
        Temp4 = "0" + Temp4
    End If
    temp5 = Trim(Str(Minute(ZDateTime)))
    If Len(temp5) = 1 Then
        temp5 = "0" + temp5
    End If
    Worksheets("Contact_Log").Cells(i, 1).Value = Temp1 + Temp2 + Temp3 + Temp4
+ temp5 + "Z"
    Else
        Worksheets("Contact_Log").Cells(i, 1).Value = ""
    End If

    If (ContactEntry.Brg <> "") And (ContactEntry.Rng <> "") And
(ContactEntry.Unit_Lat <> "") And (ContactEntry.Unit_Lon <> "") Then
        ContactEntry.Option2.Value = True
        Call ComputeBTN_Click
    End If

    If ContactEntry.LocalOption = True Then
        ContactTime = DateValue(ContactEntry.Date_contact) +
TimeValue(ContactEntry.Time_contact)

```

```

    EntryTime = DateValue(ContactEntry.Date_entry) +
TimeValue(ContactEntry.Time_entry)
    Else
        Zulu = ((Worksheets("Settings").Range("ZuluCorr").Value) / 24)
        ContactTime = DateValue(ContactEntry.Date_contact) +
TimeValue(ContactEntry.Time_contact) - Zulu
        EntryTime = DateValue(ContactEntry.Date_entry) +
TimeValue(ContactEntry.Time_entry) - Zulu
    End If

Worksheets("Contact_Log").Cells(i, 3).Value = Format(ContactTime, "MM/DD/YY")
Worksheets("Contact_Log").Cells(i, 4).Value = Format(ContactTime, "HH:MM")
Worksheets("Contact_Log").Cells(i, 16).Value = Format(EntryTime, "MM/DD/YY")
Worksheets("Contact_Log").Cells(i, 17).Value = Format(EntryTime, "HH:MM")
Worksheets("Contact_Log").Cells(i, 5).Value = ContactEntry.Unit
Worksheets("Contact_Log").Cells(i, 6).Value = ContactEntry.Refpt
Worksheets("Contact_Log").Cells(i, 7).Value = ContactEntry.Unit_Lat
Worksheets("Contact_Log").Cells(i, 8).Value = ContactEntry.Unit_Lon
Worksheets("Contact_Log").Cells(i, 9).Value = ContactEntry.Sensor
Worksheets("Contact_Log").Cells(i, 10).Value = ContactEntry.Conf
Worksheets("Contact_Log").Cells(i, 11).Value = (ContactEntry.Brg)
Worksheets("Contact_Log").Cells(i, 12).Value = (ContactEntry.Rng)
Worksheets("Contact_Log").Cells(i, 13).Value = ContactEntry.Cont_Lat
Worksheets("Contact_Log").Cells(i, 14).Value = ContactEntry.Cont_Lon
Temp = ContactEntry.Crs + "deg / " + ContactEntry.Speed + "kts"
Worksheets("Contact_Log").Cells(i, 15).Value = Temp
Worksheets("Contact_Log").Cells(i, 2).Value = ContactEntry.ClassBox
Worksheets("Contact_Log").Cells(i, 18).Value = ContactEntry.Amp
If (ContactEntry.Cont_Lat = "") Then
    Worksheets("Contact_Log").Cells(i, 19).Value = ContactEntry.BrgError
Else
    Worksheets("Contact_Log").Cells(i, 19).Value = ContactEntry.PosError
End If
ContactEntry.ZuluOption = True
ContactEntry.Hide

```

Problematic lines of code
highlight in red

```

TempTime = (Now() + Worksheets("Settings").Range("Offset").Value)
    If (LogRowNum = 0) And (ContactTime <= TempTime) Then
        Call CurrentDisplay
    Else
        Worksheets("Settings").Range("CurrTime").Value = ContactTime
        Call startUpdate
    End If
'Check if dimensionsless shock is excessive
    If (ContactEntry.ClassBox <> "") Then

```

```

If (Worksheets("Scratch").Range("Track_Options").Value <> 1) Then
  For i = 1 To 4
    TrackNum = Trim("Track" + Trim(Str(i)))
    If (Worksheets("Scratch").Range(TrackNum).Value = ContactEntry.ClassBox)
Then
      TargetNum = Trim("Target" + Trim(Str(i)))
      TargetName = Worksheets("Scratch").Range(TrackNum).Value
      Set Sheet1 = Worksheets(TargetNum)
      RowFound = False
      Set result = Sheet1.Range("A:A").Find(nrow)
      rn = result.Row
      If Not result Is Nothing Then
        If Sheet1.Cells(rn, 20) > 10 Then
          MsgBoxText = "Based upon time/distance considerations, the last contact
report on " + TargetName
          MsgBoxText = MsgBoxText & Chr(10) & "is UNLIKELY to be correlated with
prior contact on " + TargetName + "."
          MsgBoxText = MsgBoxText & Chr(10)
          'WarningForm.TextBox1.Text = MsgBoxText
          'WarningForm.Show
          MsgBoxText = MsgBoxText & Chr(10) & "Possible explanations include:"
          MsgBoxText = MsgBoxText & Chr(10) & "1. Last contact report is false or on a
different target (MOST LIKELY explanation)."
          MsgBoxText = MsgBoxText & Chr(10) & "2. Prior contact report is false."
          MsgBoxText = MsgBoxText & Chr(10) & "3. Assumed target speed is too low."
          MsgBoxText = MsgBoxText & Chr(10) & "4. Assumed positional/bearing error is
too small."
          MsgBoxText = MsgBoxText & Chr(10) & "5. Other data entry error on last
contact report."
          MsgBoxText = MsgBoxText & Chr(10)
          MsgBoxText = MsgBoxText & Chr(10) & "Do you wish to reclassify/modify last
contact report?"
          Resp = MsgBox(MsgBoxText, vbYesNo, "Warning!")
          If Resp = 6 Then 'Yes response
            Call Modify_contact(Sheet1.Cells(rn, 1))
          End If
        End If
      End If
    End If
  Next i
End If
Unload ContactEntry
End If
End Sub

```

Conditional check for
Dshock > 10

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BIBLIOGRAPHY

- Daniel H. Wagner Associates, Inc. Dual-Velocity Integrated Ornstein-Uhlenbeck Kalman Filter. <http://www.wagner.com/technologies/datafusion-tracking/dvioustracker.html> (accessed April 27, 2011).
- Department of the Navy. "The Navy Unmanned Undersea Vehicle (UUV) Master Plan." 2004, 9–11.
- Destroyer Squadron Seven (CDS-7). COMDESRON SEVEN – Official Site. <http://www.public.navy.mil/surfor/cds7/Pages/default.aspx> (accessed May 1, 2011).
- Eagle, James. "Kalman Filters." Naval Postgraduate School OA 4607 Course Lecture Notes, September 2010.
- Kirk, Kevin M. "ASW eFusion: Description and User's Manual (Draft Version)." Alexandria, Virginia: CNA, November 2005.
- Mann, Joelle J. "ASW fusion on a PC." Naval Postgraduate School Master's Thesis, June 2004.
- SPAWAR. Global Command and Control System. [http://www.public.navy.mil/spawar/productsServices/Pages/GlobalCommandandControlSystem-Maritime\(GCCS-M\).aspx](http://www.public.navy.mil/spawar/productsServices/Pages/GlobalCommandandControlSystem-Maritime(GCCS-M).aspx) (accessed April 26, 2011).
- U.S. Navy. Commander, Submarine Force U.S. Pacific Fleet. <http://www.csp.navy.mil/CTF-34/index.shtml> (accessed May 2, 2011).
- Vebber, Paul W. "An Examination of Target Tracking in the Antisubmarine Warfare System Evaluation Tool (ASSET), Naval Postgraduate School Master's Thesis, 1991.
- Wagner, Daniel H. "Naval Tactical Decision Aids." Military Operations Research Lecture Notes. September 1989.
- Waltz, Edward, L. and Dennis M. Buede. "Data Fusion and Decision Support For Command and Control." *IEEE Transactions on Systems, Man, and Cybernetics* SMC-16, no. 6, 1986: 865–867.
- Washburn, Alan. "A Short Introduction to Kalman Filters." Naval Postgraduate School, 2004.

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